Sandia National Laboratories

MatSeis: A Seismic Toolbox for MATLAB

J. Mark Harris and Christopher J. Young

Sandia National Laboratories

Sponsored by DOE contract DE-AC04-94AL85000
CTBT R&D Program, ST485D

ABSTRACT

To support the signal processing and data visualization needs of CTBT related projects at SNL, a MATLAB based GUI was developed. This program is known as MatSeis. MatSeis was developed quickly using the available MATLAB functionality. It provides a time-distance profile plot integrating origin, waveform, travel-time, and arrival data. Graphical plot controls, data manipulation, and signal processing functions provide a user friendly seismic analysis package. In addition, the full power of MATLAB (the premier tool for general numeric processing and visualization) is available for prototyping new functions by end users. This package is being made available to the seismic community in the hope that it will aid CTBT research and will facilitate cooperative signal processing development.

OBJECTIVES

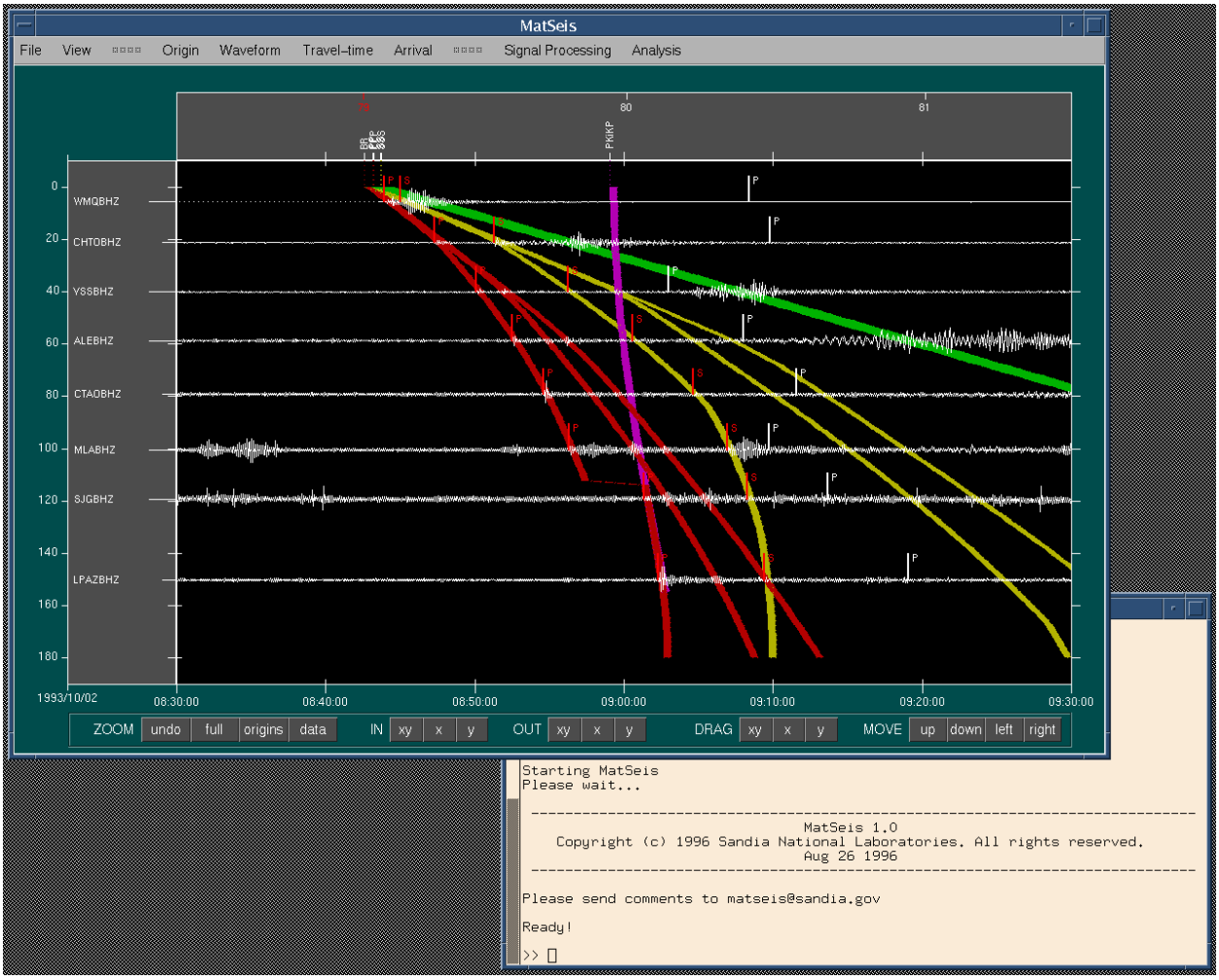
- Database access for MATLAB
- Time-distance profile data display
- Signal processing development platform

I. DEVELOPMENT

We developed MatSeis to meet the above objectives. MatSeis is a Graphical User Interface (GUI) programmed using MATLAB handle graphics. The initial MatSeis prototype was completed very quickly by taking advantage of MATLAB functionality.The prototype consisted of Oracle CSS 3.0 database access routines, a data profile display, and simple plot manipulation controls. Once the power of MatSeis was seen, its functions were expanded and performance improved to make it a more general seismic data visualization, processing, and analysis tool. We developed GUIs for reading and manipulating origin, waveform, travel-time, and arrival data. Interfaces to MATLAB and custom signal processing routines were added. Start-up configuration and system functions such as printing were also developed. Finally, we improved performance by converting often-used routines to compiled C MEX-files.

II. DESCRIPTION

MatSeis is executed from a command terminal window running MATLAB. The main graphical window has function menus at the top, push-button controls across the bottom, and the main time-distance display in the center. An example screen print showing both the MatSeis display window and the MATLAB command window is shown here.



MatSeis Display

The main MatSeis display window consists of several linked plots showing the four basic types of data: origins, waveforms, travel-time curves, and arrivals. Origin IDs are displayed at the correct time in the upper plot. The central plot is organized as distance-from-origin vs. time, so that travel-time curves are drawn in a familiar fashion. Waveforms are superimposed over the travel-time curves. In this way phase arrival structure in the data is readily apparent.

MATLAB Interface

Since MatSeis is based upon MATLAB, the standard MATLAB environment is available from the command window. In fact, MatSeis is just a collection of functions which are executed in MATLAB. Anything done by a MatSeis GUI may also be done from the command line (although it may be very tedious), and data stored in MatSeis may be accessed on the command line for manual processing. For instance, raw waveform data may be entered directly into a prototype processing routine and the results plotted using MATLAB or entered back into MatSeis.

Zooming

- Push-button control
- Zoom IN using the mouse
- Zoom OUT to twice the original size
- DRAG the plot with the mouse
- MOVE the view one-half screen in any direction
- 10-level UNDO function
- Zoom to all origins or waveforms

Menus

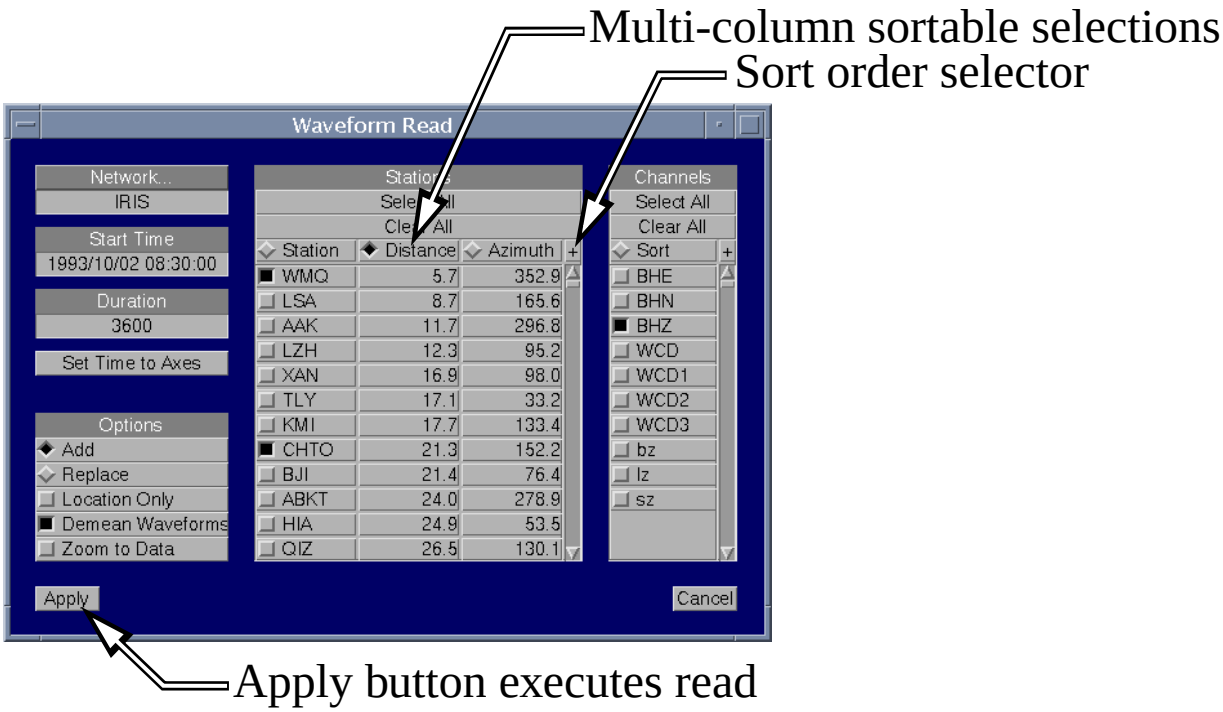
- File and View provide administration functions
- Origin, Waveform, Travel-time, and Arrival data menus
- Signal Processing and Analysis menus

Data Popups

- Left mouse button creates data object popup window
  -> Manipulation of data object
  (raise, lower, edit, delete, etc.)
- Double-click performs the first action on the popup
- Center mouse button lowers object in the plot
- Right mouse button initiates the standard edit function for the object

Setup Windows

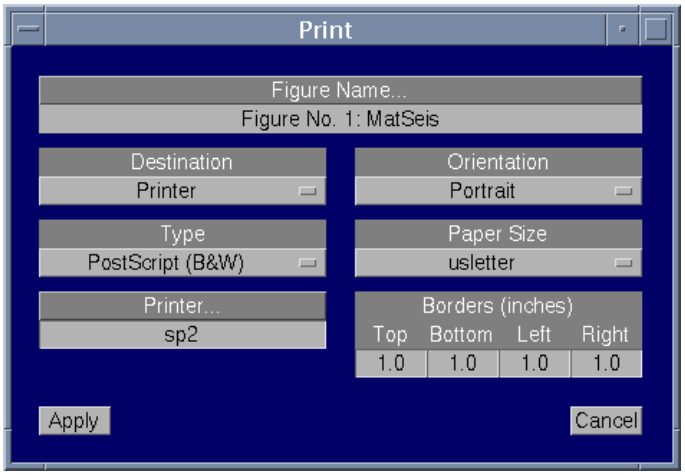
Many operations require parameters to be entered before the action is applied. These items may use a setup window like the *Waveform>Read* window shown here. Menu items followed by an ellipsis (...) will generate a setup window. Typically, the Apply button must be pressed to execute these actions. Menu items with no ellipsis execute the action immediately.



Utilities

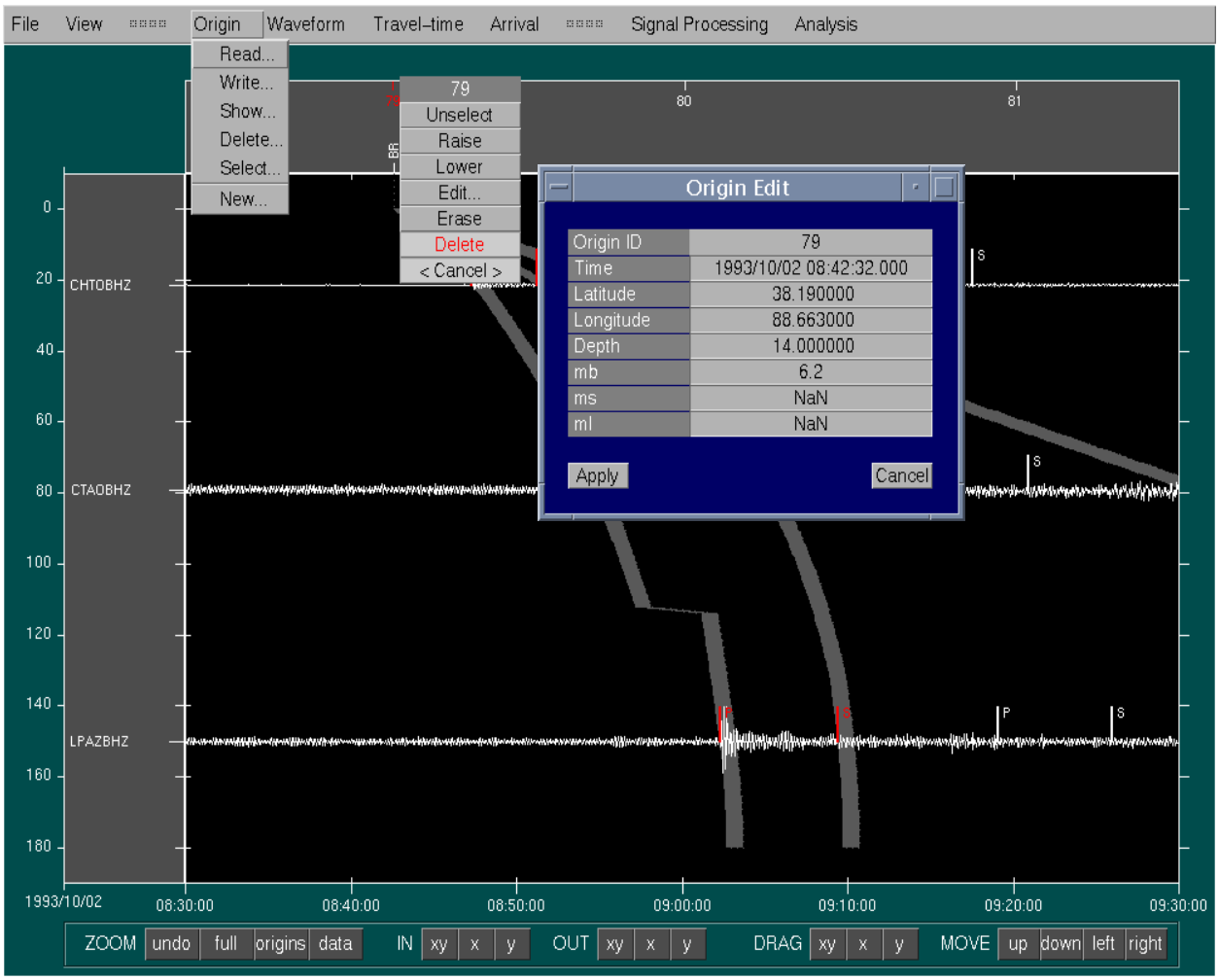
Various graphical utility functions are provided, such as the database setup window for the Oracle database interface.

The print window allows printing to a printer in black and white or color, or to a file in several file formats.



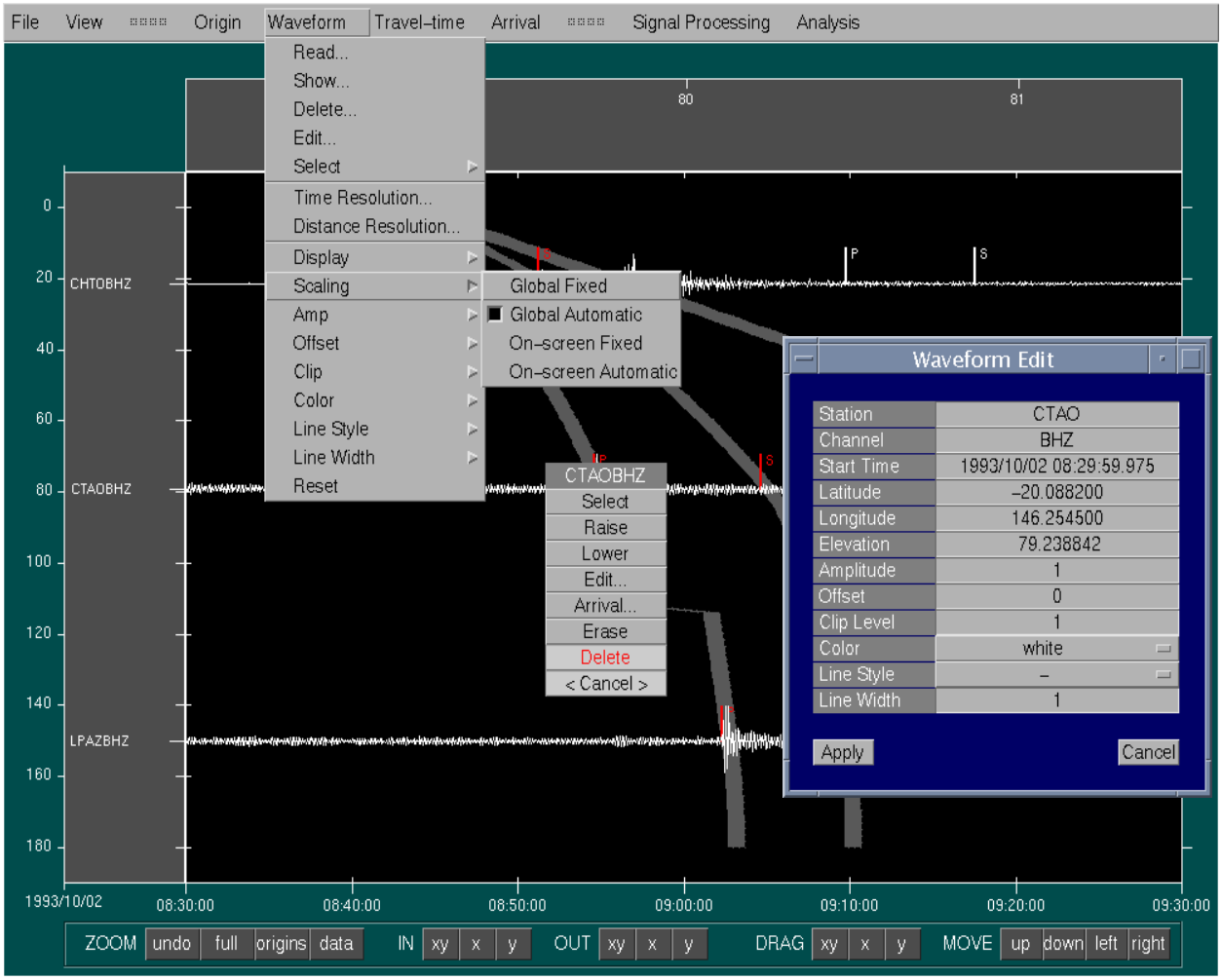
Origins

Event origins are a key component of the MatSeis display. Origin time is used to align travel-time curves on the plot. Distance from the origin to each station is used to align waveforms. The origin that is currently “selected” for alignment is highlighted red. If no origin is selected, waveforms are drawn in a strip-chart fashion with no travel-time curves. The origin menu, popup, and edit window are shown here. Origin data may be edited and written to the database and new origins may be created using these functions.



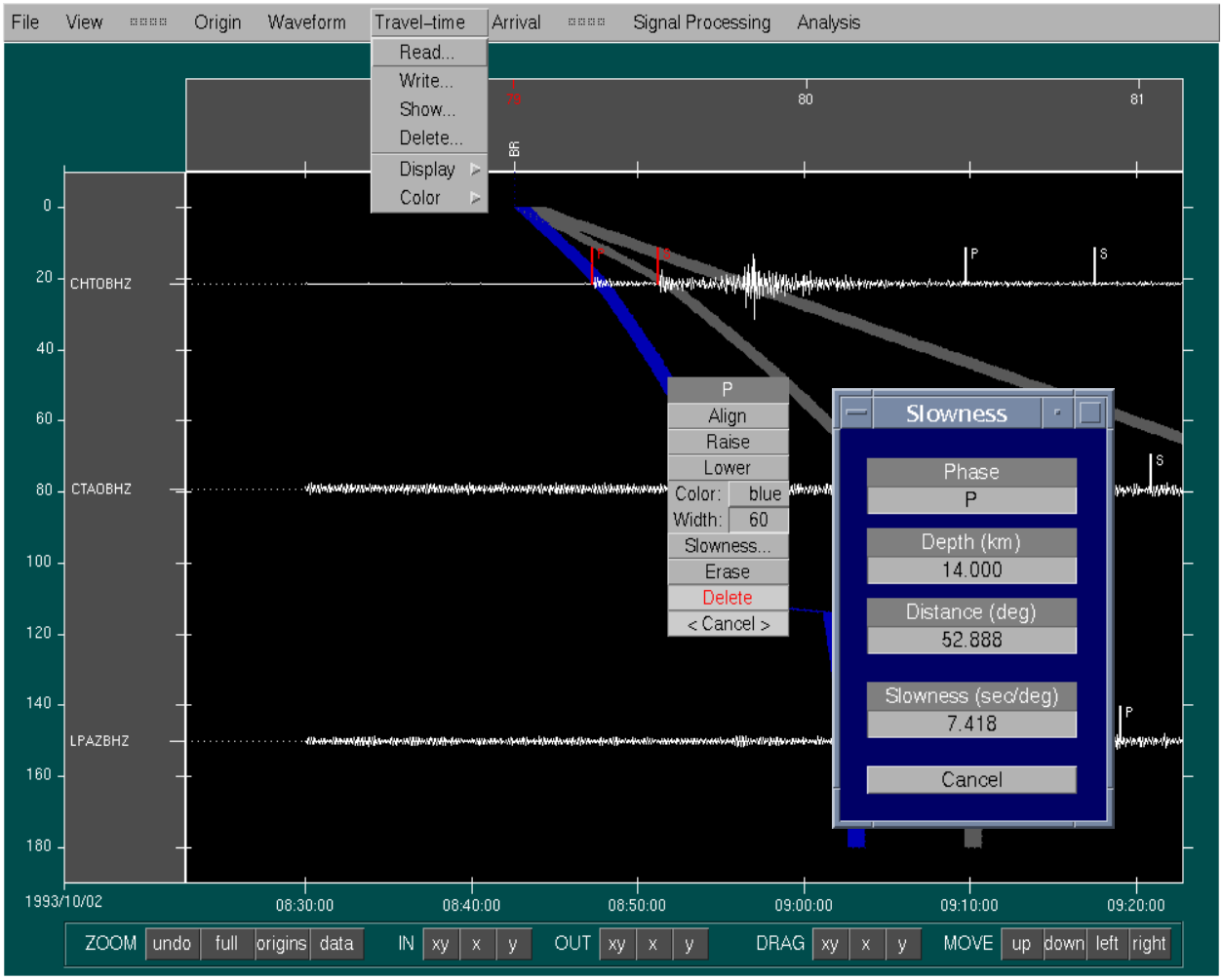
Waveforms

Seismograms are the primary seismic data object. Many waveform parameters may be manipulated in MatSeis to help visualize seismograms. Amplitude, color, and line width may be set, either globally or individually. Waveforms may also be easily selected for use by signal processing functions.

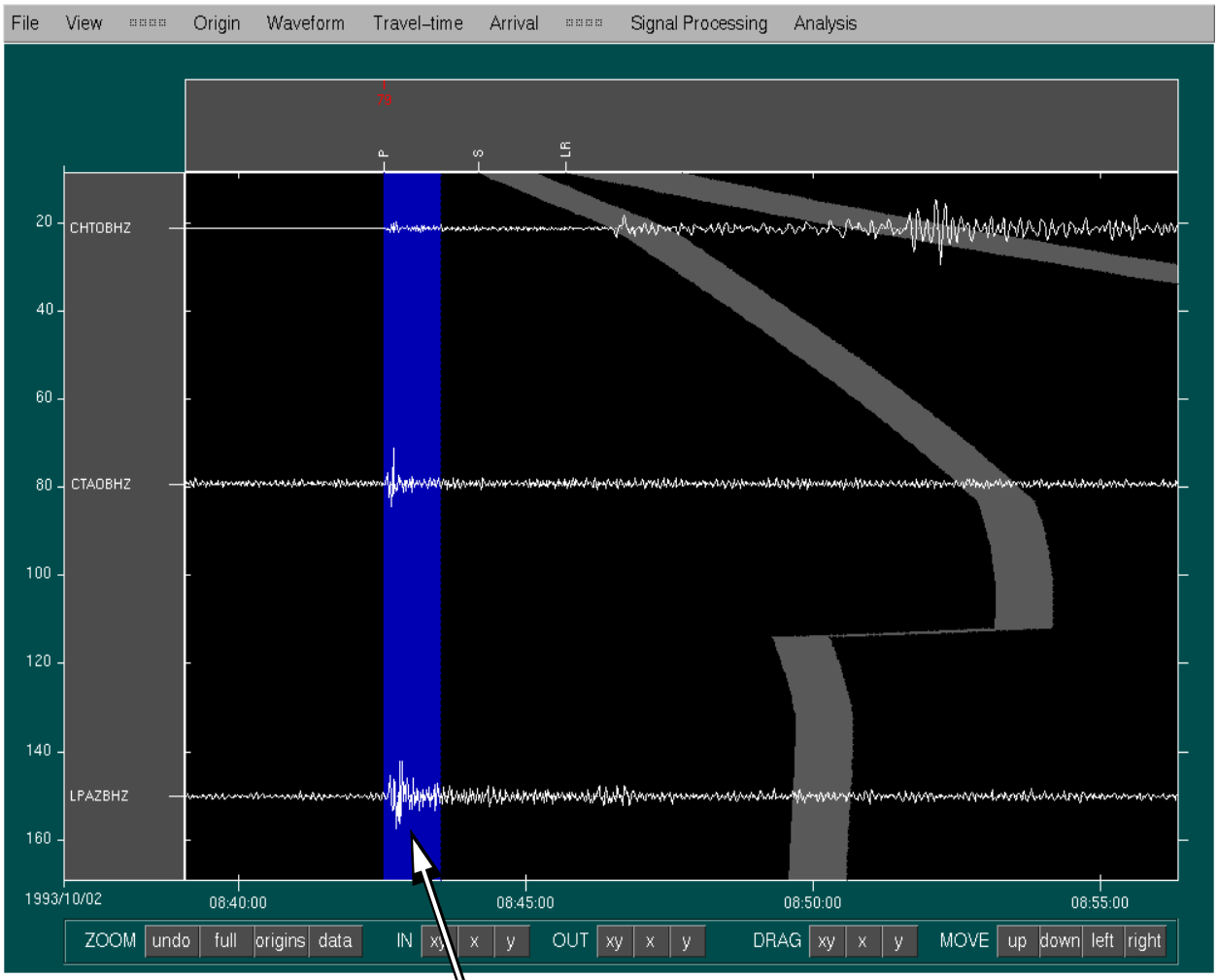


Travel-time curves

Theoretical phase arrival times are an important tool in seismic analysis. MatSeis displays travel-times as prominent features of the time-distance profile. Travel-time curves are drawn as solid patches aligned on the current origin time. Waveforms and arrivals are drawn above the travel-time curves so that features in the data are readily identifiable.



MatSeis has the ability to align the time axis of the data plot on any of the travel-time curves (or on a reduction velocity). This is very useful for examining common waveform features, such as the ‘P’ phase arrivals as shown here. The plot alignment is also used by the signal processing routines for selecting waveform segments to process.

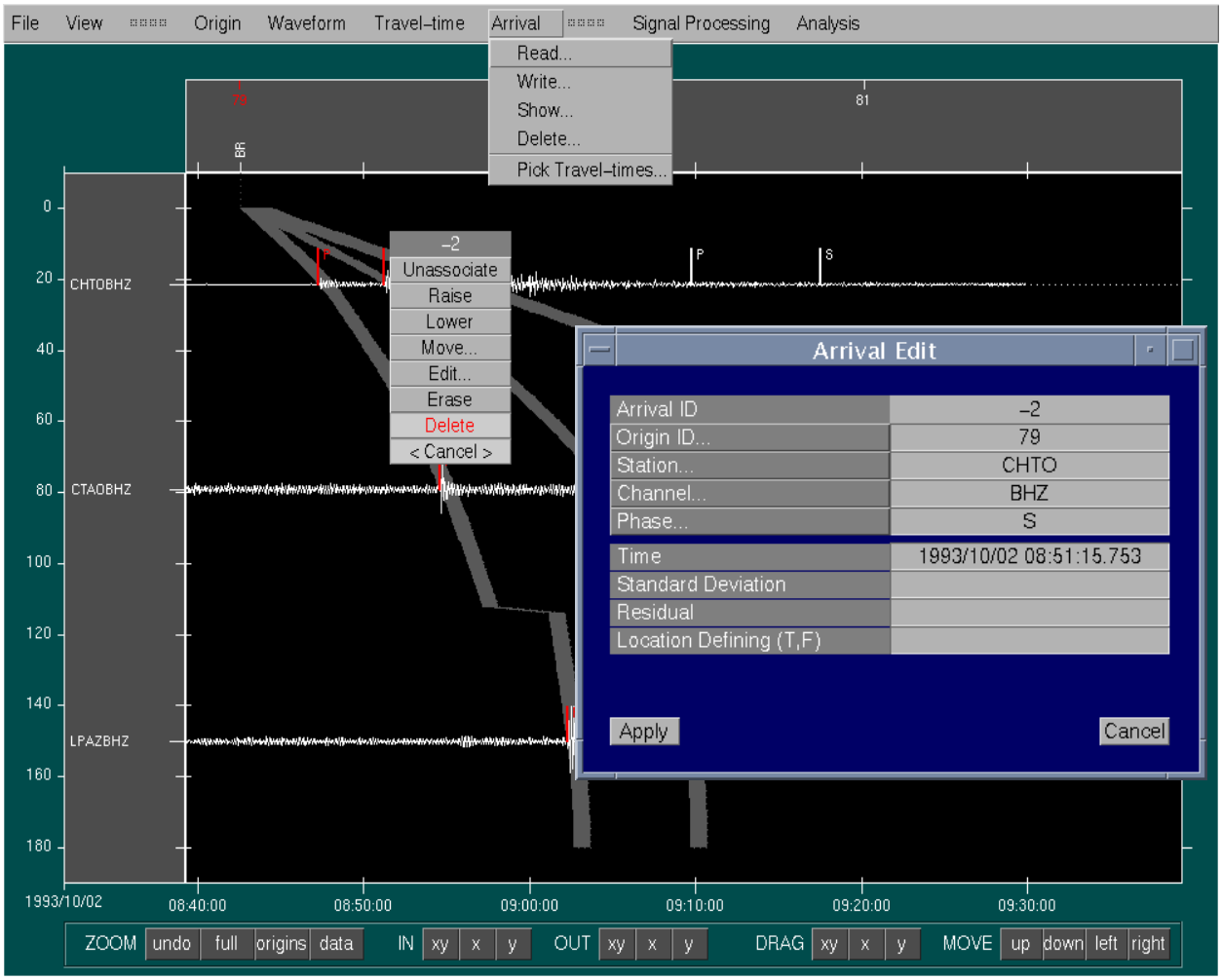


Plot aligned on ‘P’ travel-time curve

Several travel-time data file formats are supported, including IASP91, an ascii matrix format, and a “Master Image” format used by the WCEDS project. IASP91 files are included with MatSeis.

Arrivals

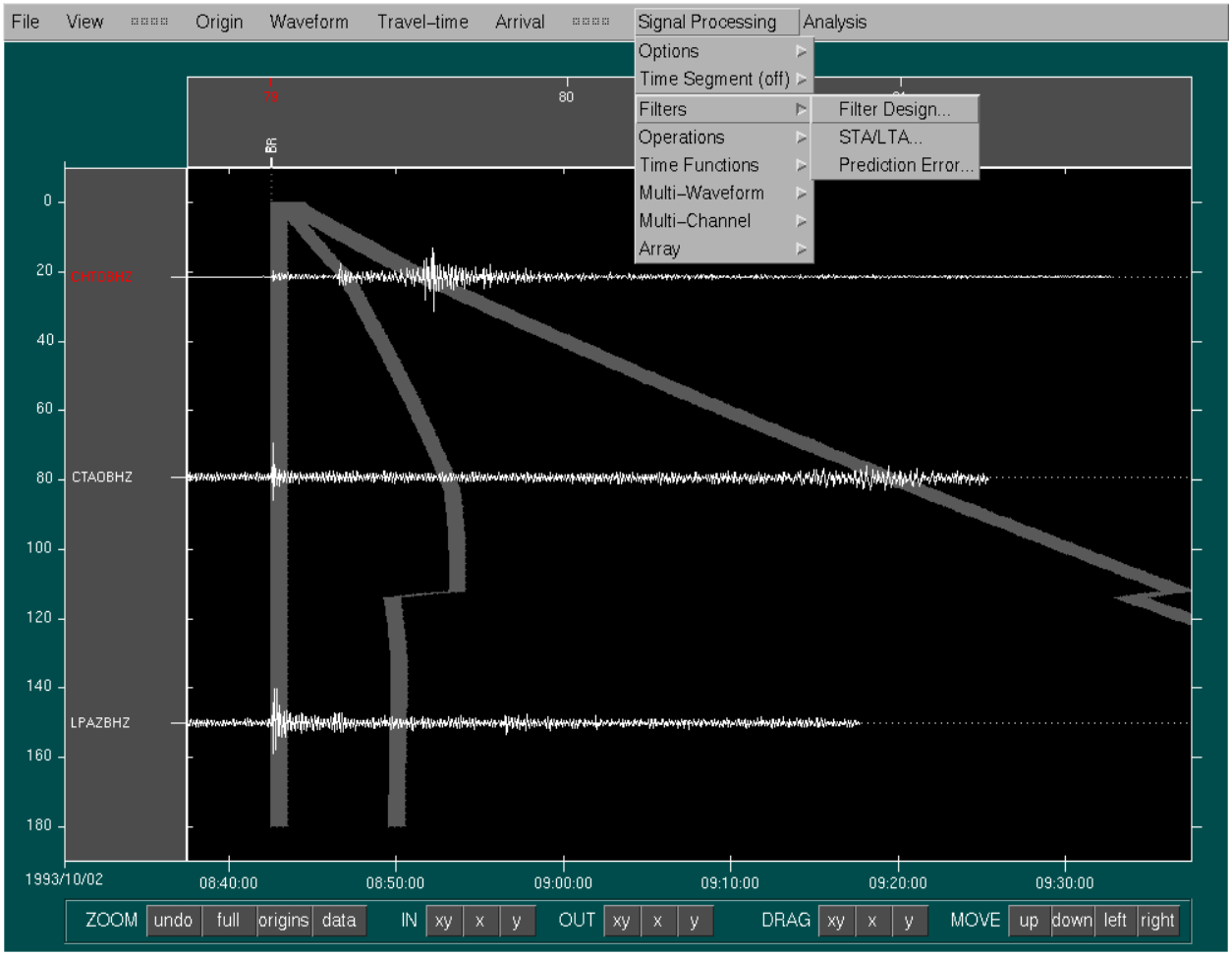
Phase arrival measurements are also supported in MatSeis. Like the other data objects, arrivals may be read from and written to the database. Arrivals may also be interactively picked on a waveform, then edited and saved.



Arrivals that are associated with the current origin are colored red, arrivals associated with some other origin are white, and unassociated arrivals are yellow.

III. SIGNAL PROCESSING AND ANALYSIS

Signal processing is an important component of MatSeis. MATLAB provides a rich environment of signal processing functions, and new functions may be rapidly prototyped. MATLAB offers “toolboxes” of functions for many types of processing. Signal processing, statistics, wavelet, neural network, fuzzy logic, and many other toolboxes are available. A menu of signal processing and analysis routines is available for immediate use.



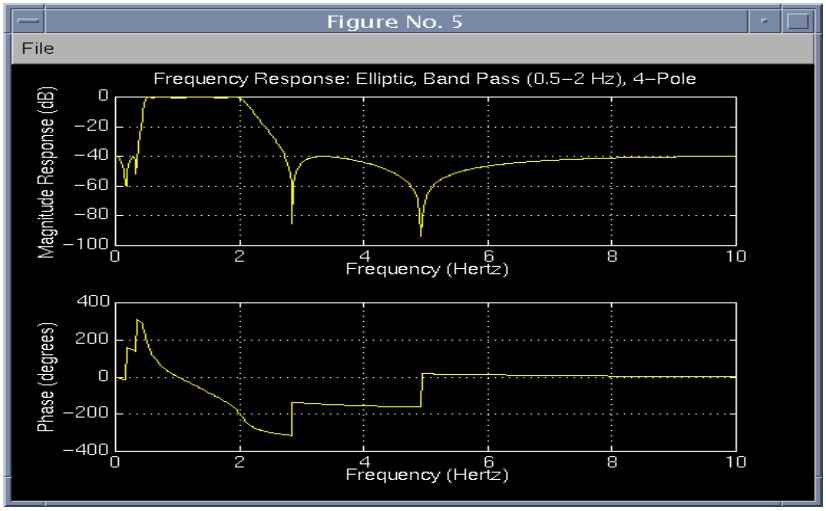
Operation

- Select waveforms using *Waveform>Select* or the waveform popup
- Set *Signal Processing>Options* as desired
  -> Replace waveforms or create new waveforms
- Set *Signal Processing>Time Segment* as desired
  -> Select the time window to process or process the whole waveform
- Select the processing routine from the *Signal Processing* menu
- Some functions prompt for additional parameters in a setup window, while others execute immediately

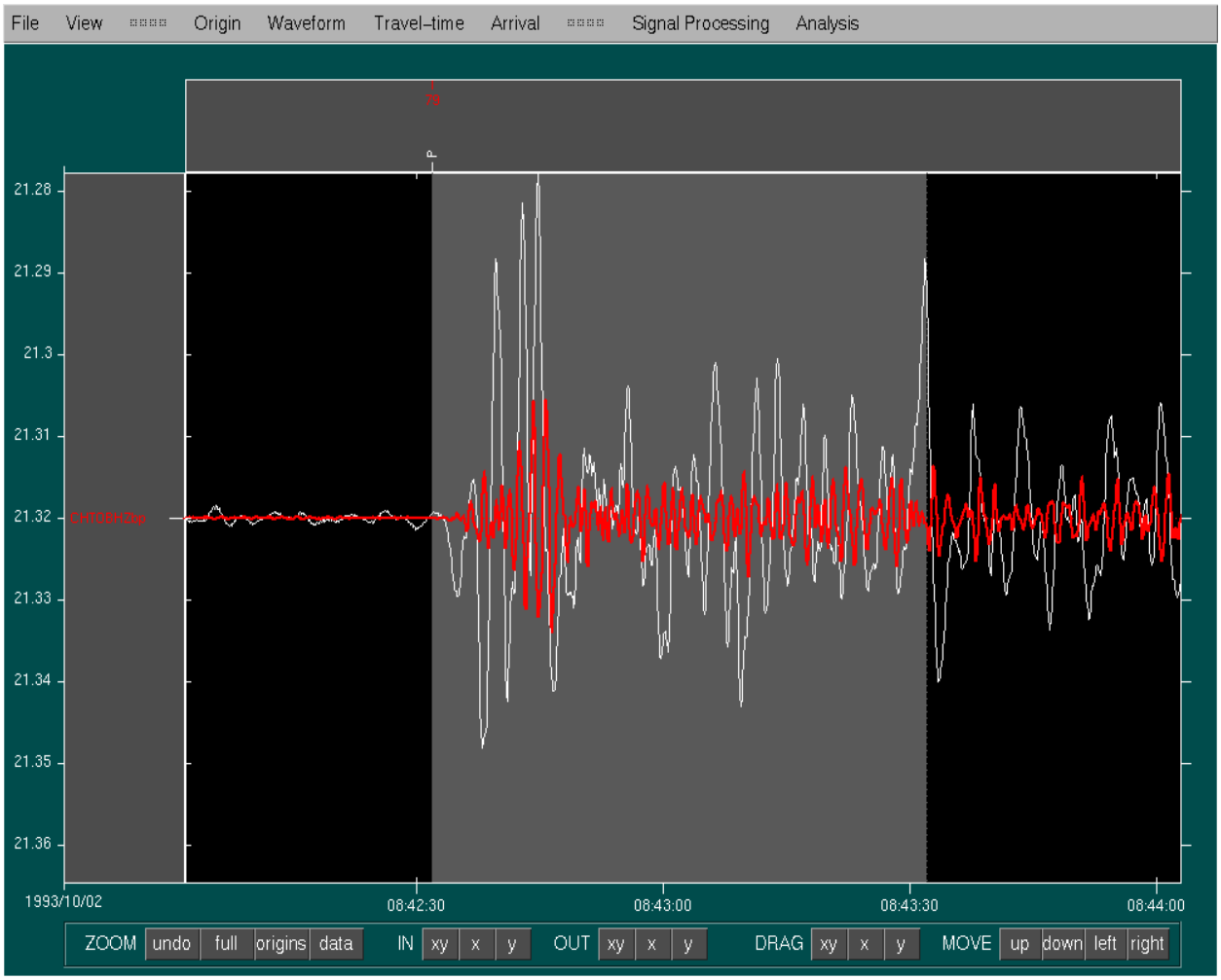
Filters

MATLAB provides a number of digital filter design techniques in the Signal Processing Toolbox, such as Butterworth, Chebyshev, Elliptic, and FIR. The *Signal Processing>Filters>Filter Design* window combines these techniques and allows you to set filter parameters as appropriate.

The performance of the filter may be checked by plotting frequency response, impulse response, and poles and zeros in the z-domain. An example frequency response is shown here.



The filter may then be applied to the selected waveform. In this example, the raw data is shown in white and the filtered data in red.



Arithmetic Operations

Many arithmetic operations may be applied to waveforms, such as absolute value, DC offset, gain, clip, negate, sign, square, and square root. A custom function may be designed using MATLAB syntax with *Signal Processing>Filters>Custom Function.*

Other simple operations, such as demean, difference, derivative, and windowing, are also available on the menu.

Time Functions

Simple timing functions are provided. You may cut a time segment from the waveform, shift it, or resample it at a new sample rate.

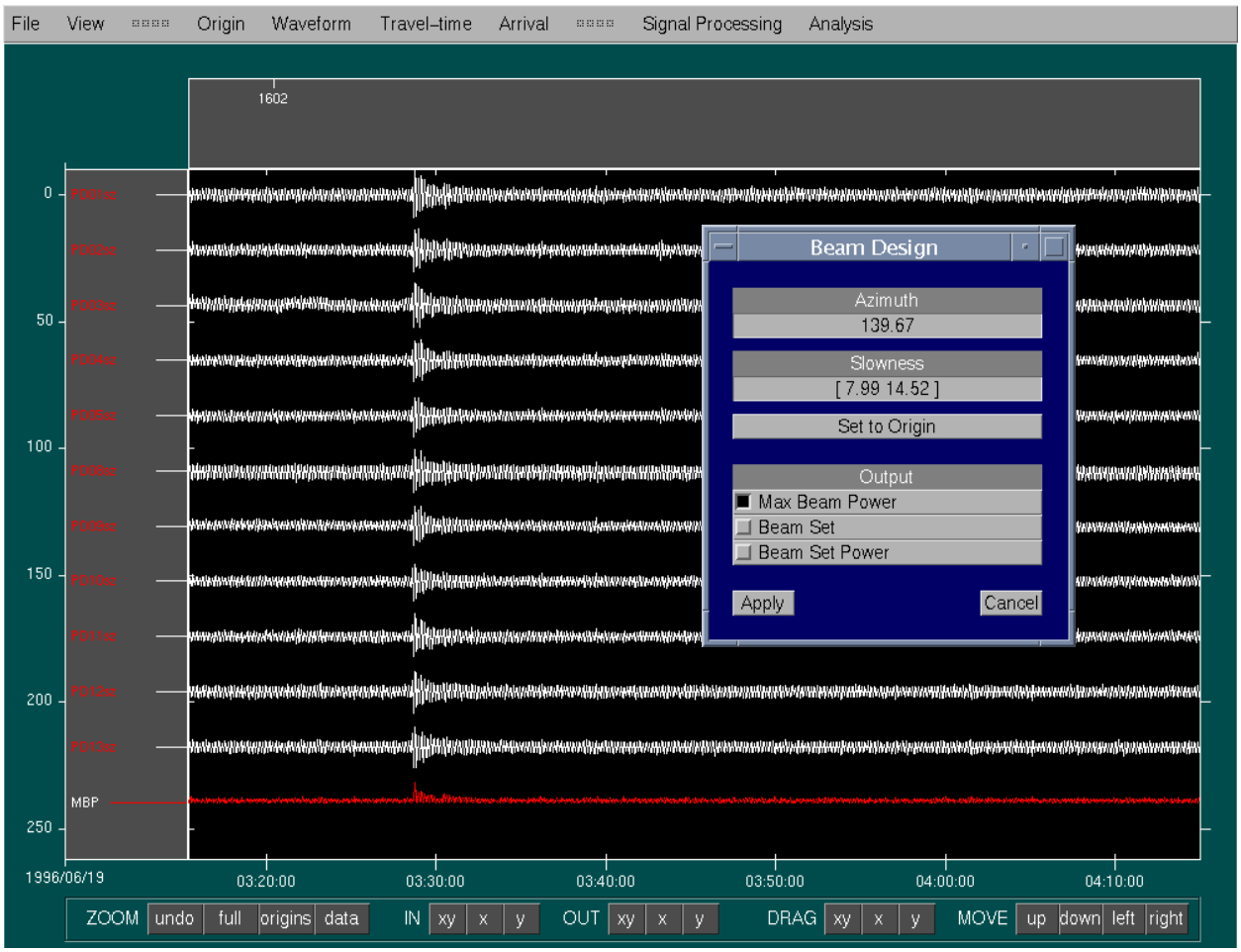
Multi-Waveform and Multi-Channel

Some functions operate on multiple waveforms. The *Multi-Waveform* functions (*Sum*, *Product*, and *Concatenate*) use all selected waveforms as input and produce one output. The Multi-Channel functions (*Sum* and *Product*) use all selected channels of each selected station as input and produce one output for each station.

Array Processing

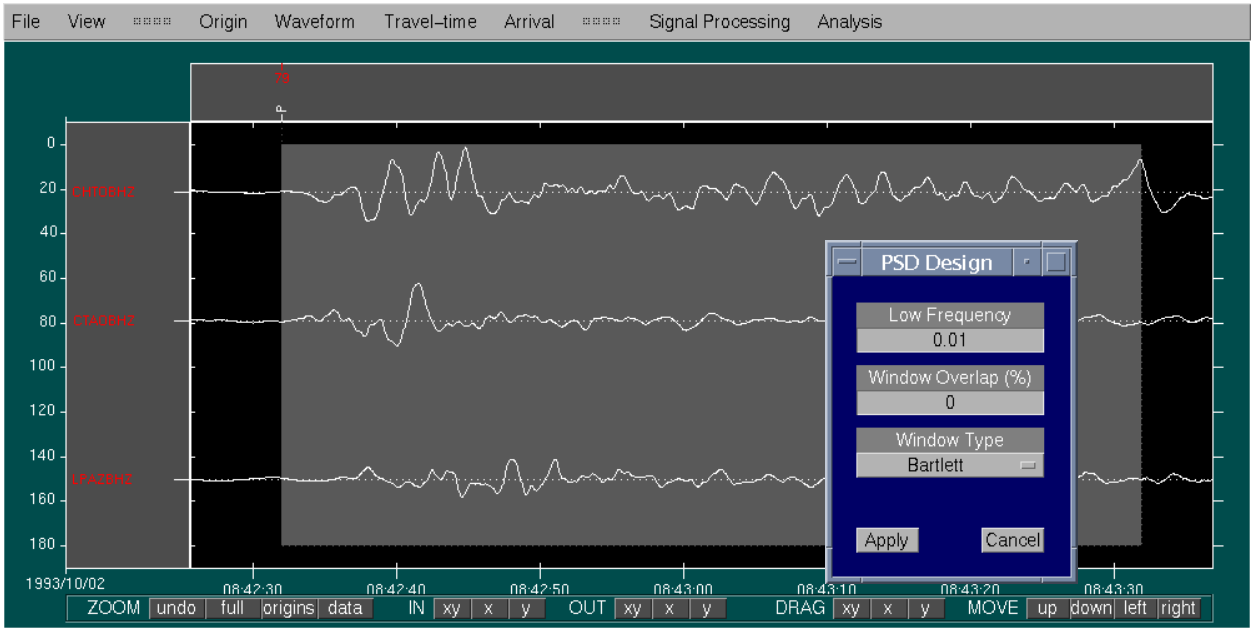
Array processing includes a time-delay beamformer and a spacial coherence routine based upon principal component analysis. The beamformer will form beams for each of a set of azimuth and slowness values, which may be specified as a MATLAB expression. The azimuth and slowness may also be set to the current origin. In this case the slowness values are calculated from each travel-time curve currently visible.

The beamformer will output the set of beams calculated or the maximum beam power of the set of beams. New waveforms are created for these results. A graphical display of the signal power of each beam is also available.

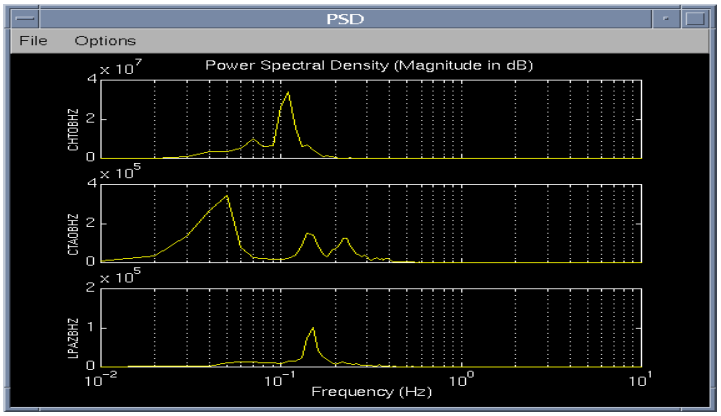


Spectral Analysis

Basic spectral analysis is easily performed with MatSeis. The *Analysis>Power Spectral Density* function calculate the PSD of the selected waveforms. In this example, the waveforms are aligned on ‘P’, and the time segment is set to the axis limits. The low frequency limit (which determines the number of points in each window) is set to 0.01 Hz. Window overlap is set to zero, and a Bartlett windowing function is used.

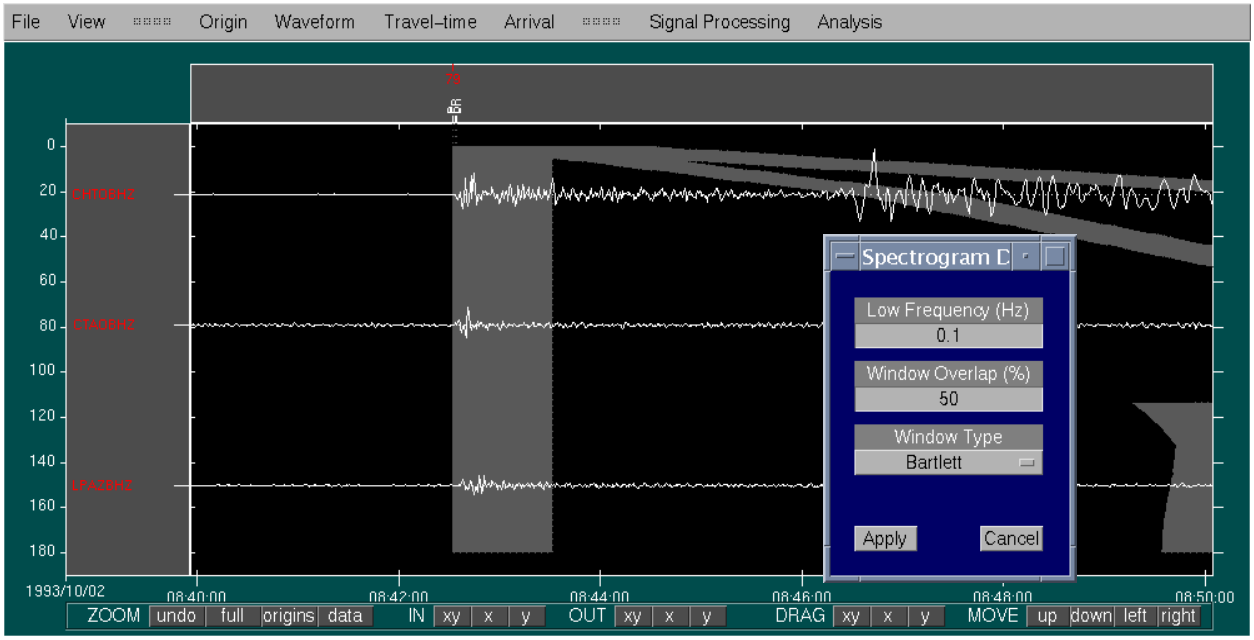


The output shows the power spectral density for the above data.

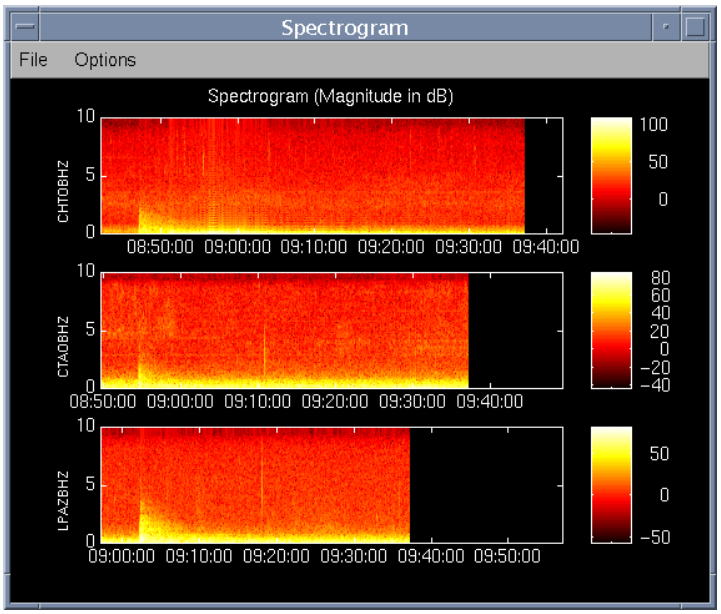


Spectrogram

Time-frequency analysis is easily performed using the *Analysis>Spectrogram* function.



The spectrogram output is also time-aligned. Here the ‘P’ arrivals are clearly visible in each of the waveforms.



IV. CUSTOMIZATION AND EXTENSION

- Start up configuration
  -> Environment variables
  -> Configuration file
- Templates provided
  -> Signal processing
  -> Database access
- Full source code provided for user modification

V. AVAILABILITY

System Requirements

- Currently compiled and tested for SunOS and Solaris
- Hardware platform must support MATLAB
- MATLAB version 4.2c
- MATLAB Signal Processing Toolbox version 3.0b
- C compiler (if compiling on a new platform)

Web Page

Information and software are available on the CTBT R&D home page:
http://www.ctbt.rnd.doe.gov/ctbt/data/matseis/matseis.html

Email Address

Please send comments and questions to matseis@sandia.gov

Mailing List

A mailing list for MatSeis users has been set up at Sandia. To subscribe, send email to majordomo@sandia.gov
with “subscribe matseis-users [address]” as the message body.

VI. CONCLUSIONS AND RECOMENDATIONS

- MATLAB has been very useful to the CTBT R&D project team at Sandia
- MatSeis has provided better data access, manipulation, and algorithm prototyping than other available packages
- MatSeis is being made available to the seismic community
- Additional features will be added to MatSeis in a synergistic way by any and all users
- Sandia will help to make user enhancements available on the MatSeis home page
- Future work at Sandia
  -> Adding signal processing routines as needed
  -> Expanding database editing
  -> Incorporating signal measurement functions (e.g. amplitude, period, first motion)